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CLINICAL RESEARCH

Contemporary Incidence, Predictors, and Outcomes of Acute Kidney Injury in Patients Undergoing Percutaneous Coronary Interventions

Insights From the NCDR Cath-PCI Registry

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Objectives This study sought to examine the contemporary incidence, predictors and outcomes of acute kidney injury in patients undergoing percutaneous coronary interventions.

Background Acute kidney injury (AKI) is a serious and potentially preventable complication of percutaneous coronary interventions (PCIs) that is associated with adverse outcomes. The contemporary incidence, predictors, and outcomes of AKI are not well defined, and clarifying these can help identify high-risk patients for proactive prevention.

Methods A total of 985,737 consecutive patients underwent PCIs at 1,253 sites participating in the National Cardiovascular Data Registry Cath-PCI registry from June 2009 through June 2011. AKI was defined on the basis of changes in serum creatinine level in the hospital according to the Acute Kidney Injury Network (AKIN) criteria. Using multivariable regression analyses with generalized estimating equations, we identified patient characteristics associated with AKI.

Results Overall, 69,658 (7.1%) patients experienced AKI, with 3,005 (0.3%) requiring new dialysis. On multivariable analyses, the factors most strongly associated with development of AKI included ST-segment elevation myocardial infarction (STEMI) presentation (odds ratio [OR]: 2.60; 95% confidence interval [CI]: 2.53 to 2.67), severe chronic kidney disease (OR: 3.59; 95% CI: 3.47 to 3.71), and cardiogenic shock (OR: 2.92; 95% CI: 2.80 to 3.04). The in-hospital mortality rate was 9.7% for patients with AKI and 34% for those requiring dialysis compared with 0.5% for patients without AKI ($p < 0.001$). After multivariable adjustment, AKI (OR: 7.8; 95% CI: 7.4 to 8.1, $p < 0.001$) and dialysis (OR: 21.7; 95% CI: 19.6 to 24.1; $p < 0.001$) remained independent predictors of in-hospital mortality.

Conclusions Approximately 7% of patients undergoing a PCI experience AKI, which is strongly associated with in-hospital mortality. Defining strategies to minimize the risk of AKI in patients undergoing PCI are needed to improve the safety and outcomes of the procedure.
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Acute kidney injury (AKI) after a percutaneous coronary intervention (PCI) is a common and serious complication of the procedure and is associated with an increased risk of myocardial infarction (MI), dialysis, and death (1–17). Even small increases in serum creatinine have been associated with increased hospital length of stay and excess costs (18–22). Accordingly, multiple stakeholders have emphasized AKI prediction and prevention as a major healthcare priority because therapeutic options are limited once AKI develops.

Despite its importance, the reported incidence of AKI after PCI varies widely, from 3% to 19%. This wide variation is thought to be a consequence of estimates from single-center studies or studies that preceded the current use of volume expansion protocols and iso-osmolar contrast agents. Furthermore, previous studies have used varying definitions of AKI, making it difficult to compare AKI rates across different studies and populations. Defining the prevalence and consequences of AKI in a large national sample of centers is critically important for identifying the value of national efforts to address AKI as a potential quality metric. Recently, there has been widespread adoption by the nephrology and critical care communities of the Acute Kidney Injury Network (AKIN) criteria to provide uniform standards for the definition and classification of AKI (23). These parameters updated the original RIFLE criteria to be readily obtainable worldwide and broad enough to accommodate variations in clinical presentations among different age groups, locations, and clinical settings (24,25). The AKIN criteria have also recently been embraced by the cardiology community and are used in most current studies of AKI in the cardiology literature (26–28).

Abbreviations and Acronyms

ACC = American College of Cardiology
AKI = acute kidney injury
AKI-D = acute kidney injury requiring dialysis
AKIN = Acute Kidney Injury Network
CI = confidence interval
CKD = chronic kidney disease
eGFR = estimated glomerular filtration rate
MI = myocardial infarction
NCDR = National Cardiovascular Data Registry
OR = odds ratio
PCI = percutaneous coronary intervention
STEMI = ST-segment elevation myocardial infarction

Better defining the current incidence and predictors of AKI using the AKIN criteria in a large, real-word registry of patients undergoing PCI and its impact on clinical outcomes can provide a context for addressing this complication and serve as a stimulus to improve prevention efforts. Using the National Cardiovascular Data Registry (NCDR), the world's largest PCI registry, we evaluated the incidence of AKI using the AKIN criteria and examined the patient factors associated with AKI and the association of AKI with in-hospital morbidity and mortality.

Methods

Study population. The NCDR Cath-PCI registry, co-sponsored by the American College of Cardiology (ACC) and the Society for Cardiovascular Angiography and Interventions, has been previously described (29,30). The registry collects data on patient and hospital characteristics, clinical presentation, treatments, and outcomes associated with PCIs from >1,200 U.S. hospitals. The data are entered into ACC-certified software at participating institutions. There is a comprehensive data quality program, including both data quality report specifications for data capture and transmission and an auditing program. The data collected are exported in a standard format to the ACC Heart House (Washington, DC). The complete definitions of all variables were prospectively defined by a committee of the ACC and are available at the ACC NCDR Website.

For this study, we identified all patients undergoing a PCI between June 1, 2009, and June 30, 2011, enrolled in the NCDR (N = 1,254,089). We excluded patients without a pre-procedure and a peak post-procedure in-hospital serum creatinine level (n = 239,025; 19%), patients undergoing multiple PCIs during a single hospitalization (n = 32,999; 2.6%), and patients currently on dialysis at the time of their PCI (n = 24,517; 2%). The final analytical cohort included 957,548 patients undergoing PCI (Fig. 1).

Baseline kidney function. Using the pre-procedure serum creatinine level as baseline, we calculated the estimated glomerular filtration rate (eGFR) (in ml/min/1.73 m^2) using the Modification of Diet in Renal Disease equation and classified patients as having normal baseline renal function (eGFR, >60), mild chronic kidney disease (CKD) (eGFR, 45 to 60), moderate CKD (eGFR, 30 to 45), or severe CKD (eGFR, <30).

Primary outcomes: AKI and AKI requiring dialysis. The primary outcome was AKI, using the change from pre-procedure to peak serum creatinine levels. We classified AKI using the AKIN criteria (AKI stage 1, ≥0.3 mg/dl absolute or 1.5 to 2.0-fold relative increase in serum creatinine; AKI stage 2, >2- to 3-fold increase in serum creatinine; AKI stage 3, >3-fold increase in serum creatinine or serum creatinine >4.0 mg/dl with an acute increase of >0.5 mg/dl). AKI requiring dialysis (AKI-D) was an in-hospital outcome identified using a pre-defined NCDR data element for acute

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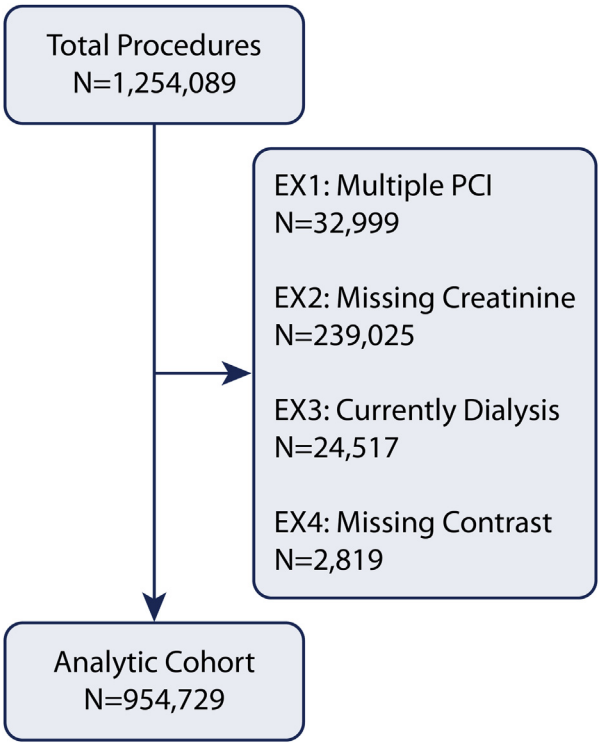

Figure 1. Population Selection Flow Diagram

Initial cohort and cohort exclusions. EX = exclusion; PCI = percutaneous coronary intervention.

or worsening renal failure necessitating new renal dialysis. Patients with AKI-D were included in the AKI group but were also examined separately to identify independent predictors of the occurrence of the need for dialysis.

Secondary outcomes: clinical endpoints. Secondary outcomes of the study, used to establish the clinical importance of AKI, were the following: 1) in-hospital major bleeding, defined as a ≥3-g/dl decrease in hemoglobin, transfusion of whole packed red blood cells, or an intervention to stop the bleeding within 72 h of the procedure; 2) in-hospital MI, defined as an increase in serum troponin or creatine kinase (or whatever the specific biomarkers were) >3 times the upper limit of normal within 24 h post-PCI or, in patients with elevated baseline cardiac biomarkers, a characteristic increase and decrease in cardiac biomarkers; and 3) in-hospital mortality.

Statistical analysis. Patients were stratified by the absence of AKI; AKI stages 1, 2, and 3, or AKI-D after PCI. Differences between groups were compared using chi-square tests for categorical variables and the Wilcoxon rank sum or Kruskal-Wallis test for continuous variables.

We considered important baseline patient characteristics and clinically relevant variables for inclusion in models examining risk factors for AKI or AKI-D. Candidate variables included age, sex, body mass index, intra-aortic balloon pump insertion before the procedure, congestive heart failure (CHF) on presentation, diabetes, hypertension, previous MI, previous PCI, previous coronary artery bypass grafting, previous cerebrovascular disease, previous peripheral arterial disease, chronic lung disease, unstable angina/non–ST-segment elevation myocardial infarction (STEMI), STEMI, shock on presentation, cardiac arrest on presentation, anemia (hemoglobin <10 mg/dl), contrast dose in 75-ml increments, multiple procedures, and patients transferred from an outside hospital. Logistic regression with the generalized estimating equation method was used to account for within-hospital clustering.

To assess the association between AKI or AKI-D and in-hospital major bleeding, MI, and death, we used multivariable analyses with generalized estimating equation to adjust for associations clustered within hospitals. The NCDR PCI mortality model variables (31) were used for risk-adjusting MI and death and included age, race, sex, body mass index, previous congestive heart failure, previous valve surgery, previous cerebrovascular disease, peripheral vascular disease, chronic lung disease, previous PCI, diabetes, admission symptom presentation, cardiogenic shock, pre-operative intra-aortic balloon pump, ejection fraction, New York Heart Association functional class, coronary lesion >50%, highest pre-procedure Thrombolysis In Myocardial Infarction flow, and PCI status (elective, urgent, emergent, salvage). For the major bleeding endpoint, the validated NCDR bleeding model was used for risk adjustment, which included age, sex, previous heart failure, GFR, peripheral vascular disease, no previous PCI, NYHA/Canadian Cardiovascular Society functional class IV heart failure, STEMI, non-STEMI, and cardiogenic shock (32).

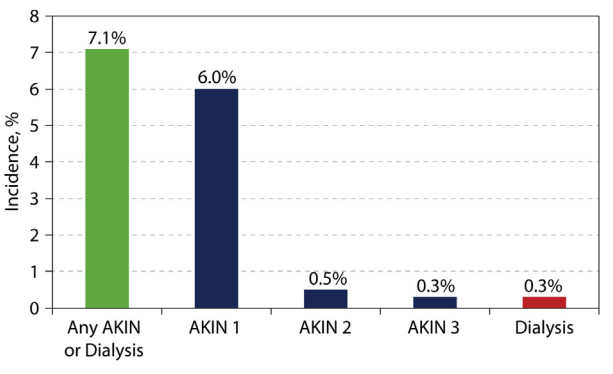

Figure 2. Incidence of Acute Kidney Injury or Dialysis

The incidence of acute kidney injury as defined by the Acute Kidney Injury Network (AKIN) definitions. AKIN 1, ≥0.3 mg/dl absolute or 1.5- to 2.0-fold relative increase in serum creatinine; AKIN 2, >2- to 3-fold increase in serum creatinine; AKIN 3, >3-fold increase in serum creatinine or serum creatinine >4.0 mg/dl with an acute increase of >0.5 mg/dl. Dialysis was an in-hospital outcome identified using a pre-defined National Cardiovascular Data Registry data element for acute or worsening renal failure, necessitating new renal dialysis.

Results

Baseline characteristics. Of the 985,737 patients in our cohort, AKI developed in 69,658 patients (7.1%): 56,850 (6%) with AKI stage 1, 4,534 (0.5%) with AKI stage 2, 2,441 (0.3%) with AKI stage 3, and 3,005 (0.3%) with AKI-D (Fig. 2). The mean ± SD age was 64.8 ± 12.2 years (Table 1), and the patients had a high prevalence of comorbidities including diabetes (35.8%), dyslipidemia (79.9%), and hypertension (81.7%). The majority of patients (71.2%) presented with acute coronary syndromes. Almost 30% of patients had CKD at baseline (eGFR ≤60 ml/min/1.73 m^2), the mean ± SD length of stay was 2.2 ± 4.4 days, and the median volume of contrast used was 185 ml (interquartile range: 140 to 250 ml).

Patients with AKI or AKI-D were significantly older than patients without AKI and were more likely to have had a history of anemia, MI, congestive heart failure, and coronary artery bypass grafting (Table 1). Patients with AKI and AKI-D were also more likely to have had a history of

Table 1. Baseline Characteristics of the Study Cohort

Variable	Total (N = 954,729)	No AKI (n = 888,023, 93.0%)	AKI Stage 1 (n = 56,850, 6.0%)	AKI Stage 2 (n = 4,534, 0.5%)	AKI Stage 3 (n = 2,441, 0.3%)	Dialysis (n = 2,881, 0.3%)	p Value
Patient characteristics							
Age, yrs	64.8 ± 12.2	64.6 ± 12.1	68.2 ± 12.5	69.1 ± 12.5	66.6 ± 12.4	68.8 ± 12.0	<0.001
Female	313,445 (32.8)	287,161 (32.3)	22,077 (38.8)	2,079 (45.9)	1,008 (41.3)	1,120 (38.9)	<0.001
Nonwhite race	109,851 (11.5)	99435 (11.2)	8,304 (14.6)	616 (13.6)	354 (14.5)	463 (16.1)	<0.001
Previous MI	284,579 (29.8)	263,024 (29.6)	18,467 (32.5)	1,407 (31.1)	741 (30.4)	940 (32.7)	0.002
Previous CHF	110,668 (11.6)	95,557 (10.8)	12,535 (22.1)	1,156 (25.5)	444 (18.2)	976 (33.9)	<0.001
Diabetes	341,934 (35.8)	309,073 (34.8)	27,543 (48.5)	2,339 (51.6)	1,189 (48.7)	1,790 (62.2)	<0.001
CVD	116,718 (12.2)	104,418 (11.8)	10,406 (18.3)	883 (19.5)	410 (16.8)	601 (20.9)	<0.001
PVD	116,948 (12.3)	104,669 (11.8)	10,273 (18.1)	907 (20.0)	419 (17.2)	680 (23.6)	<0.001
CLD	145,238 (15.2)	131,608 (14.8)	11,481 (20.2)	1,041 (23.0)	453 (18.6)	655 (22.7)	<0.001
Hypertension	780,800 (81.8)	723,062 (81.5)	49,339 (86.8)	3,877 (85.6)	2,027 (83.1)	2,495 (86.7)	<0.001
Active tobacco use	266,111 (27.9)	250,361 (28.2)	13,358 (23.5)	1,107 (24.5)	676 (27.8)	609 (21.2)	<0.001
Dyslipidemia	763,101 (80.0)	711,301 (80.2)	44,491 (78.4)	3,354 (74.2)	1,833 (75.2)	2,122 (73.8)	<0.001
Previous PCI	379,592 (39.8)	355,352 (40.0)	21,051 (37.0)	1,453 (32.1)	830 (34.0)	906 (31.5)	<0.001
Previous CABG	177,449 (18.6)	163,298 (18.4)	12,229 (21.5)	877 (19.3)	417 (17.1)	628 (21.8)	<0.001
Baseline CKD, ml/min/1.73 m^2							
Normal (eGFR ≥60)	675,826 (70.8)	641,025 (72.2)	30,307 (53.3)	2,375 (52.4)	1,634 (66.9)	485 (17.8)	<0.001
Mild (eGFR 45–60)	163,272 (17.1)	150,219 (16.9)	11,193 (19.7)	1,013 (22.3)	427 (17.5)	420 (15.4)	<0.001
Moderate (eGFR 30–45)	87,491 (9.2)	76,198 (8.6)	9,537 (16.8)	850 (18.7)	266 (10.9)	640 (23.5)	<0.001
Severe (eGFR<30)	27,980 (2.9)	20,581 (2.3)	5,813 (10.2)	296 (6.5)	114 (4.7)	1,176 (43.2)	<0.001
Presentation and hospital care							
No symptoms	90,281 (9.5)	85,244 (9.6)	4,406 (7.8)	271 (6.0)	176 (7.2)	184 (6.4)	<0.001
Atypical chest pain							
Stable angina	159,547 (16.7)	153,399 (17.3)	5,581 (9.8)	267 (5.9)	197 (8.1)	103 (3.6)	<0.001
ACS: unstable angina	347,775 (36.4)	328,505 (37.0)	17,185 (30.2)	975 (21.5)	597 (24.5)	513 (17.8)	<0.001
ACS: non-STEMI	179,191 (18.8)	161,075 (18.1)	15,237 (26.8)	1,316 (29.0)	629 (25.8)	934 (32.4)	<0.001
ACS: STEMI	149,753 (15.7)	133,341 (15.0)	12,919 (22.7)	1,613 (35.6)	794 (32.5)	1,086 (37.7)	<0.001
CHF	96,214 (10.1)	79,536 (9.0)	13,340 (23.5)	1,479 (32.7)	616 (25.2)	1,243 (43.2)	<0.001
Cardiogenic shock	17,622 (1.8)	11,746 (1.3)	3,987 (7.0)	775 (17.1)	369 (15.1)	745 (25.9)	<0.001
Cardiac arrest	17,357 (1.8)	13,378 (1.5)	2,802 (4.9)	519 (11.4)	268 (11.0)	390 (13.5)	<0.001
IABP	0	0	0	0	0	0	0
Length of stay, days	2.2 ± 4.4	2.0 ± 3.9	4.8 ± 6.2	8.6 ± 9.4	8.3 ± 14.3	15.0 ± 17.9	<0.001
Contrast volume, ml	185 (140–250)	185 (140–245)	190 (140–250)	200 (150–275)	200 (150–275)	200 (135–260)	<0.001

Values are mean ± SD, n (%), or median (interquartile range).

ACS = acute coronary syndrome; AKI = acute kidney injury; CABG = coronary artery bypass grafting; CHF = congestive heart failure; CKD = chronic kidney disease; CLD = chronic lung disease; CVD = cardiovascular disease; eGFR = estimated glomerular filtration rate; IABP = intra-aortic balloon pump; MI = myocardial infarction; PCI = percutaneous coronary intervention; STEMI = ST-segment elevation myocardial infarction.

cardiovascular disease and peripheral artery disease and to present with non-STEMI or STEMI compared with patients without AKI.

Incidence of AKI and AKI-D in patients with CKD. The incidence of AKI and AKI-D after PCI was strongly related to the severity of baseline CKD and STEMI presentation (Fig. 3). With increasing severity of baseline CKD, the incidence of AKI and AKI-D increased significantly. For example, the risk of AKI and AKI-D in patients with normal baseline renal function was 5.2% and 0.07%, respectively, compared with 26.6% and 4.3%, respectively, in patients with severe CKD at baseline (eGFR <30 ml/min/1.73 m^2). Patients with severe CKD at baseline presenting with STEMI represented the highest-risk subgroup, with an AKI incidence of 36.9% and an AKI-D incidence of 7.2%.

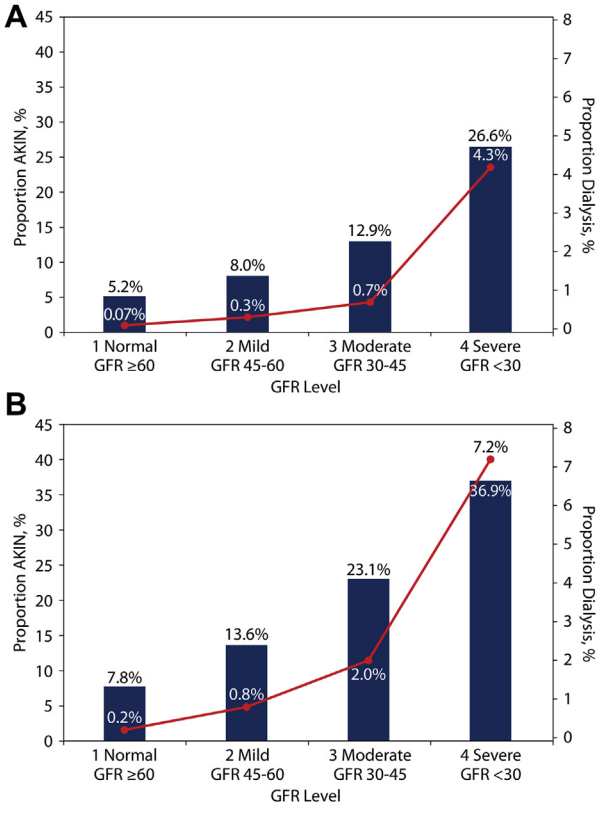

Figure 3. Incidence of AKI or Dialysis Stratified by Severity of Chronic Kidney Disease

(A) AKI and dialysis by GFR level: all patients. **(B)** AKI and dialysis by GFR level: ST-segment elevation myocardial infarction (STEMI) patients. The incidence of AKI on the **left** y-axis and dialysis on the **right** y-axis stratified by baseline chronic kidney disease as defined by a patient's GFR. GFR was calculated using the Modification of Diet in Renal Disease equation on the basis of the patient's pre-procedure serum creatinine level. **(A)** All patients. **(B)** Only patients presenting with STEMI. AKI = acute kidney injury; AKIN = Acute Kidney Injury Network; GFR = glomerular filtration rate; STEMI = ST-segment elevation myocardial infarction.

Independent predictors of AKI and AKI-D after PCI. Independent factors associated with AKI or AKI-D are shown in Figure 4. Among these factors, severe baseline CKD (odds ratio [OR]: 3.59; 95% confidence interval [CI]: 3.47 to 3.71), cardiogenic shock (OR: 2.92; 95% CI: 2.80 to 3.04), and STEMI presentation (OR: 2.60; 95% CI: 2.53 to 2.67) were associated with the greatest risk of AKI. Similarly, severe CKD (OR: 28.54; 95% CI: 25.54 to 31.96) and moderate CKD (OR: 5.47; 95% CI: 5.09 to 6.47) were also associated with the greatest risk of AKI-D.

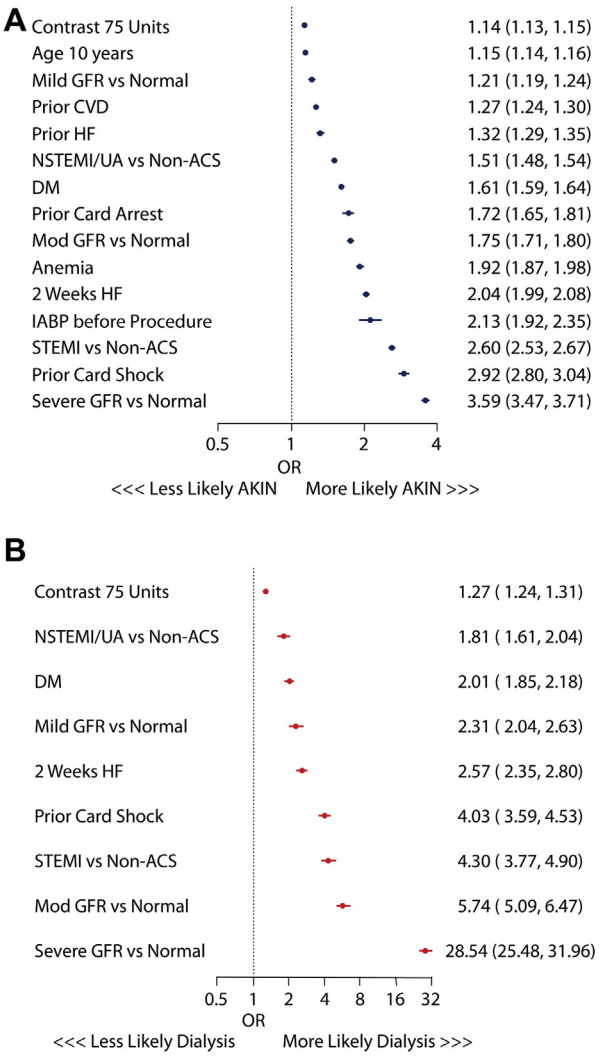

Figure 4. Independent Predictors of AKI or Dialysis

(A) Independent predictors of any AKI (including dialysis). **(B)** Independent predictors of dialysis only. Odds ratios were calculated using logistic regression with generalized estimating equation methods. ACS = acute coronary syndrome; CVD = cerebrovascular disease; DM = diabetes mellitus; HF = heart failure; IABP = intra-aortic balloon pump; NSTEMI/UA = non–ST-segment elevation myocardial infarction/unstable angina; other abbreviations as in Figure 3.

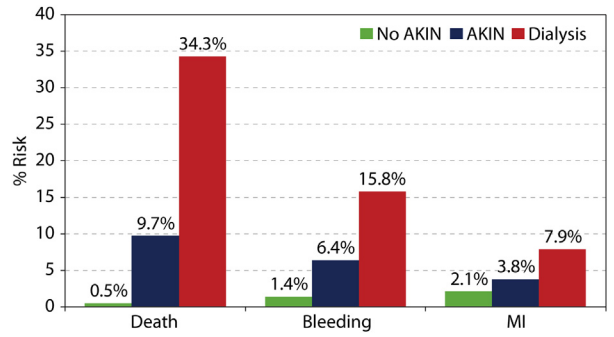

Figure 5. Risk of Death, Bleeding, and Myocardial Infarction in Patients With AKI and/or Dialysis

The incidence of death, bleeding, and MI stratified by the absence and presence of AKI and the presence of dialysis. MI = myocardial infarction; other abbreviations as in Figure 3.

Association of AKI with adverse clinical endpoints. Of the 69,658 patients in whom AKI developed after PCI, the in-hospital rates of MI, bleeding, and death was 3.8%, 6.4%, and 9.6% respectively, compared with 2.1%, 1.4%, and 0.5%, respectively, in patients in whom AKI did not develop. The rates of MI (7.9%), bleeding (15.8%), and death (34.3%) were the highest in the 3,005 patients in whom AKI-D developed (Fig. 5). When stratified by AKI severity, patients with AKI stages 2 and 3 had similar rates of death, bleeding, and MI (Table 2).

Even after adjusting for differences in baseline patient characteristics, AKI was associated with a significantly increased odds of bleeding (OR: 2.38; 95% CI: 2.27 to 2.49), MI (OR: 1.66; 95% CI: 1.58 to 1.75), and death (OR: 3.68; 95% CI: 3.49 to 3.88). Patients with AKI-D had an even higher odds of bleeding (OR: 4.56; 95% CI: 4.12 to 5.05), MI (OR: 2.70; 95% CI: 2.35 to 3.12), and death (OR: 4.56; 95% CI: 4.12 to 5.05). When stratified by AKI stages, all stages were independently associated with bleeding, MI, or death (Fig. 6).

Discussion

In this large, contemporary, real-world study evaluating patients undergoing PCI, we found that AKI developed in 7.1% of patients, of whom 0.3% required dialysis. Pre-procedure characteristics such as STEMI presentation and baseline CKD were powerful predictors of AKI and AKI-D, increasing the odds by 2- to 28-fold. In risk-adjusted analyses, AKI and AKI-D were independently associated with markedly increased risks of in-hospital major bleeding, MI, and death. Our study confirmed a high in-hospital mortality rate in patients with AKI (9.6%) or AKI-D (34.3%) compared with patients not experiencing AKI (0.5%) or AKI-D (1.1%). Collectively, these data demonstrate that AKI is common and independently associated with other adverse events and would justify a national effort to improve prevention as a foundation for greater safety and better PCI outcomes.

Table 2. Incidence of Death, Bleeding, and MI Stratified by AKIN Stages of AKI

AKIN Stage	Death, %	Bleeding, %	MI, %
NO AKI	0.5	1.4	2.1
1	6.6	5.4	3.3
2	24.6	11.4	5.9
3	23.4	9.5	5.7

AKIN = Acute Kidney Injury Network; other abbreviations as in Table 1.

The results of our study highlight the ongoing problem of 2AKI in post-PCI patients, despite increased physician awareness and measures to prevent AKI in this setting (26). Previous studies that evaluated the incidence of AKI after PCI have reported incidence rates ranging from as low as 0.7% to upward of 19% (1,2,5,6,9,10,15,16). However, most of these studies were single-center registries from more than a decade ago, and many used disparate definitions of AKI. Furthermore, in 2007, new national guidelines recommended AKI prevention strategies in patients undergoing coronary angiography, including volume expansion and low or iso-osmolar contrast agents; thus, older studies may not represent current practice (33). Our study, which included PCIs conducted between 2009 and 2011, is more likely to reflect current practices with regard to AKI reduction strategies and more accurately represent current AKI incidence rates and in-hospital outcomes.

To address the absence of a universal definition of AKI, international experts formed the AKIN (23) and developed the AKIN criteria for AKI to reflect the clinical significance of relatively small increases in serum creatinine and to enable future comparisons of the incidence, outcomes, and efficacy of therapeutic interventions for AKI (18,34,35). This standardized definition of AKI has been embraced by the nephrology and critical care community over the past 5 years and is now the predominant definition used by the cardiology community. For example, the Valve Academic Research Consortium, charged with proposing standardized consensus definitions for important clinical endpoints in future trials and registries of transcatheter aortic valve implantation, chose the AKIN criteria definition of AKI to capture this significant clinical endpoint. This consensus definition of AKI of transcatheter aortic valve implantation will allow comparison AKI rates across procedures (36,37).

To our knowledge, this is the first study to use the AKIN definition of AKI to describe the current incidence of AKI in a large cohort of post-PCI patients. Our study extends the recent report by James et al. (38), which described the incidence of AKI using AKIN criteria in a Canadian cohort undergoing coronary angiography. Of

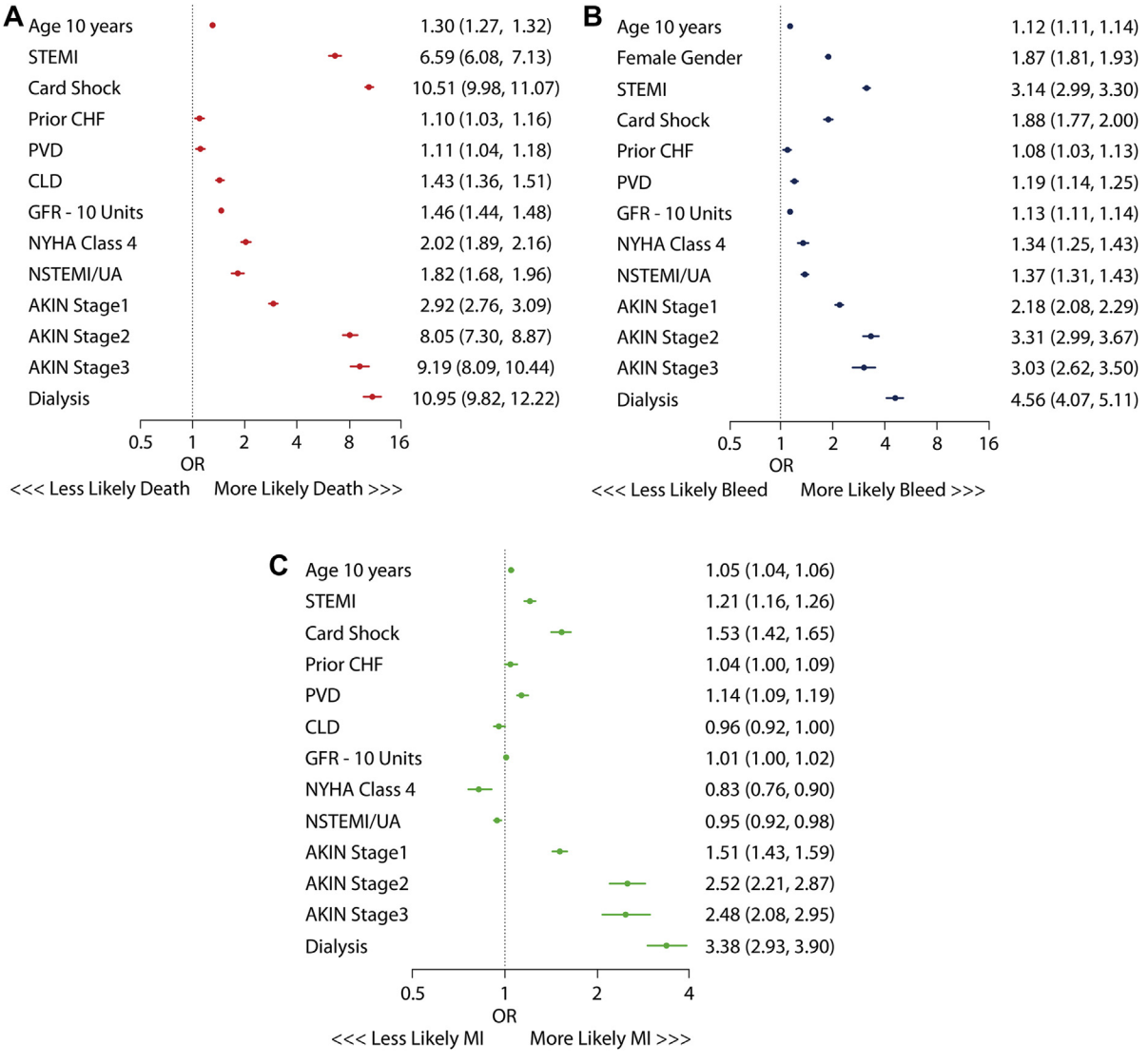

Figure 6. Independent Predictors of Bleeding, MI, and Death

(A) Independent predictors of death. **(B)** Independent predictors of major bleeding. **(C)** Independent predictors of myocardial infarction. Odds ratios were calculated using logistic regression with generalized estimating equation methods. Card Shock = cardiogenic shock; CHF = congestive heart failure; CLD = chronic lung disease; GFR - 10 = every 10-unit decrease in glomerular filtration rate; PVD = peripheral vascular disease; NYHA = New York Heart Association; other abbreviations as in Figures 3 and 5.

the 14,782 participants in that study, AKI developed in 9.6%, which was a significant risk factor for long-term mortality, end-stage renal disease, and hospitalization for cardiovascular and renal events. Our current AKI rates post-PCI will enable meaningful comparison of future studies across procedures and support quality improvement programs and research.

The update to the PCI guidelines in 2011 added an explicit statement that patients should be assessed for the risk of AKI before PCI to more accurately educate patients regarding the risks of the procedure and to consider AKI prevention strategies (39). Brown et al. (40) recently showed that reported processes and clinical leadership in AKI prevention protocols attributed to centers with lower rates of AKI. Our approach, focusing on pre-procedure variables to best estimate the periprocedure risk of AKI, can enhance the patient consent process and risk/benefit evaluations. Importantly, the large size of our cohort allowed us to also explore risk factors not only for AKI but also for AKI-D, which is often difficult to study given its low incidence, but which is a particularly dreaded complication. For example, in our study, patients with severe CKD (eGFR

<30 ml/min/1.73 m^2) had 3-fold higher odds of AKI and a 28-fold higher risk of AKI-D than patients with normal renal function. Ongoing work to internally and externally validate these models will eventually provide a bedside tool for clinicians and their patients to better quantify the risks of AKI and AKI-D in the near future.

Although AKI can occur in patients with an acute MI in the absence of contrast exposure, our study focuses on patients who are exposed to contrast during their PCI procedure (26,41). Iodinated contrast has been hypothesized to cause AKI via direct toxicity and hemodynamic changes and is the third leading cause of AKI in hospitalized patients (42–44). In accord with other studies, use of increasing volumes of contrast is associated with an independently increased risk of AKI and AKI-D in our population (2,5,16,45). Therefore, our data suggest that using the minimal amount of contrast dose to achieve optimal intraprocedural outcomes should be emphasized with each case. Further studies in CathPCIR-egistry evaluating the interaction between contrast dose, clinical presentations, and baseline factors such as diabetes and CKD are currently under way.

Our study also adds to the literature by validating the morbid association between AKI and short-term in-hospital bleeding, MI, and death in contemporary patients undergoing PCI. The most recent studies to evaluate the short-term consequences of AKI after PCI were conducted more than a decade ago as single-center studies and likely predated the use of routine hydration protocols and low osmolar contrast agents (7,17). Nonetheless, after adjustment, AKI remains strongly associated with 3- to 7-fold increased odds of in-hospital MI, 2- to 5-fold increased odds of in-hospital bleeding, and 3- to 11-fold increased odds of in-hospital death. The link between AKI and these outcomes cannot be established by the present study, but it confirms that the susceptibility to AKI is a marker for severe illness that may share a common association with poor short-term outcomes.

Study limitations. First, patients and hospitals participating in the NCDR may not be representative of all U.S. practice. However, the CathPCI Registry represents >1,200 hospitals across the United States and thus captures the majority of PCI procedures nationally. Second, we used the in-hospital pre-procedure creatinine level as the baseline value, which may not have represented the patient's true baseline serum creatinine level. It is possible that clinically unstable patients such as those patients presenting in heart failure or cardiogenic shock may have had an increased pre-procedure serum creatinine level. This would have underestimated the true magnitude of the serum creatinine increase and biased our results toward the null; however, we observed strong associations of AKI with adverse clinical outcomes. Also, we were unable to ascertain the timing of the peak serum creatinine level, and therefore the association of the peak creatinine with the PCI procedure could not be determined. Because the creatinine level peaks 3 to 5 days after the procedure, we may have underestimated the true prevalence of AKI. However, our finding of significantly increased morbidity and mortality with AKI using our definition suggests that we have identified a clinically important subset of patients with AKI. Third, we did not have data on intravenous administration of fluid, concomitant use of renal toxic medications or potentially renal protective medications, type of contrast media used (e.g., iso-osmolar, low osmolar), or exposure to other contrast procedures during the hospitalization. Finally, although our multivariable models adjusted for a large number of known predictors of AKI, the possibility of unmeasured confounding cannot be eliminated.

Conclusions

In a large national cohort study of post-PCI patients, we found that AKI developed in 7.1% of patients, 0.3% of whom required acute dialysis. In risk-adjusted models, clinical factors such as STEMI presentation and baseline CKD markedly increased the risk of the development of AKI or AKI-D. In addition, patients with AKI or AKI-D in the hospital experienced very high rates of in-hospital bleeding, MI, and death. By using standard criteria to define AKI, our study can be compared with other clinical cohorts and validates the use of such criteria for AKI as an independent predictor of adverse events. Defining more effective strategies to minimize the risk of AKI in patients undergoing PCI is needed.

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